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ESTABLISHMENT OF NATIONAL EMISSION STANDARDS FOR STATIONARY SOURCES. VOLUME III. MUNICIPAL INCINERATORS

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ESTABLISHMENT OF NATIONAL EMISSION STANDARDS FOR STATIONARY SOURCES

Volume III Municipal Incinerators

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1.0 INTRODUCTION

The amount of solid waste currently generated in the United States municipalities is over 200 million tons per year or about one annual ton per person. Today only eight to ten percent of this waste is processed in municipal incinerators.[1] This is partly due to the fact that only a portion of generated solid wastes are collected for disposal. Some 50 percent of household, commercial, and industrial wastes which would otherwise become municipality wastes are disposed of by the person(s) generating the waste. Open burning, open dumping, household refuse grinders, and apartment incinerators are presently-utilized alternatives. However, increases in population, an expected three percent annual per capita solid waste generation factor, and more stringent air and water pollution regulations could rapidly shift solid waste management toward efficiently operated municipal incinerators. Another increasingly evident economic consideration is one of urban land use.

Solid waste requiring disposal is increasing at the rate of seven million tons per year, while the area available for economic disposal by landfill is rapidly dwindling. An alternative is to incinerate an increased percentage of this material. Of course, the air pollution problem would grow

proportionately unless new, more effective and efficient burning processes were to be adopted. However, incineration is an increasingly attractive solution, and it becomes still more attractive economically as land values and transportation costs continue to rise. The fact that incineration facilities can be located near population centers and require greatly reduced land areas in comparison to landfills enhances their attractiveness to urban planners. In spite of the air pollution problems, incineration is expected to continue as an important method of disposal in the decades ahead.

The A.D. Little study[2] showed that an incinerator capacity of some 90,000 Tons Per 24-hour Day (TPD) was presently existing and active in the United States. A mathematical model, constructed specifically for this study, projected an increased active incinerator capacity of some 310,000 TPD total by the year 2000. The model reflected historical trends in incinerator construction as affected by per-capita waste generation and population growth, and was further augmented by consideration of decreasing land availability and the rapidly increasing population density projected for the future. For purposes of credibility, incinerator air pollution emission data were collected from

a wide variety of sources and correlated, as nearly as possible, with refuse composition and incinerator design characteristics and operating parameters. Estimates of the potential pollution load, both uncontrolled (furnace emissions) and abated by air pollution control (APC) devices (stack emissions), were provided by combining the resulting emission factors with the present and future forecast of the incinerator inventory. Consideration was given to the effects of changing refuse composition. The estimates for the reference year (1968) and the projected year (2000) were summarized by pollutant, (see Table below).

TABLE 1.1 ESTIMATED INCINERATOR EMISSIONS
(thousands of tons per year)

Pollutant	1968 Emissions Estimate		2000 Emissions Estimate	
	Furnace	Stack	Furnace	Stack
Mineral Particulate	90	56	708	118
Combustible Particulate	38	32	131	49
Carbon Monoxide	280	280	829	829
Hydrocarbons	22	22	64	64
Sulfur Dioxide	32	32	161	160
Nitrogen Oxides	26	22	147	114
Hydrogen Chloride	8	6	219	147
Volatile Metals (lead)	0.3	0.3	0.055	0.025
Polynuclear Hydrocarbons	0.01	0.005	0.03	0.009
Total	496.	450.	2259.	1481.

The Little incinerator inventory identified most, if not all, of the municipal systems now operating or under construction in the United States. The 364 locations include those units which have been temporarily shut down or permanently closed for economic reasons or for air pollution deficiencies.

2.0 PROCESS DESCRIPTION

Incineration is a controlled combustion process for burning solid, liquid, or gaseous combustible waste to gases and to a residue containing little or no combustible material. When solid waste is exposed to a turbulent atmosphere for a critical time period at an elevated temperature, combustion occurs. During combustion, moisture is evaporated, and the combustible portion of the solid waste is vaporized and then oxidized. Concurrent reactions are the oxidation of metals and the oxidation of such elements as sulfur and nitrogen. Carbon dioxide, water vapor, ash, and noncombustibles are the major end products of combustion.

The combustion processes take place in the furnace of [illegible] incinerator, which includes the grates and combustion chambers. There are numerous designs or configurations of furnaces to accomplish combustion, and, currently no one design can be considered the best.

Furnaces commonly used for the incineration of municipal solid waste are the vertical circular furnace, the multicell rectangular furnace, the rectangular furnace, and the rotary kiln furnace.[3]

The vertical circular furnace is usually refractory lined. Solid waste is charged through a door or lid in the upper part (usually the ceiling) and drops onto a central cone grate and the surrounding circular grate. Underfire forced air is the primary combustion air and also serves to cool the grates. As the cone and arms rotate slowly the fuel bed is agitated and the residue works to the sides where it is discharged, manually or mechanically, through a dumping grate on the periphery of the stationary circular grate. Stoking doors are provided for manual agitation and assistance in residue dumping if required. Overfire air is usually introduced to the upper portion of the circular chamber. A secondary combustion chamber is adjacent to the circular chamber. Many furnaces of this design are in operation.

The multicell rectangular type, also called the mutual assistance furnace, may be refractory lined or water cooled; it contains two or more cells set side-by-side, and each cell normally has rectangular grates. Solid waste is usually charged through a door in the top of each cell. Generally, the cells of the furnace have a common secondary combustion chamber and share a residue disposal hopper.

The rectangular furnace is the most common form in recently constructed municipal incinerators. Several grate systems are adaptable to this form. Commonly, two or more grates are arranged in tiers so that the moving solid waste is agitated as it drops from one level to the next level. Each furnace has only one charging chute. Secondary combustion

is frequently accomplished in the zone toward the gas exit of the furnace.

A rotary kiln furnace consists of a slowly revolving inclined kiln that follows a rectangular furnace where drying and partial burning occurs. The partially burned waste is fed by moving grates into the kiln where cascading action exposes unburned material for combustion. Final combustion of the combustible gases and suspended combustible particulates occurs in the mixing chamber beyond the kiln discharge. The residue falls from the end of the kiln into a quenching trough.

The grate system must transport the solid waste and residue through the furnace, and, at the same time, promote combustion by adequate agitation and passage of underfire air. The degree and methods of agitation on the grates are important. The abrupt tumbling encountered when burning solid waste drops from one tier to another will promote combustion. Abrupt tumbling,however, may contribute to entrainment of excessive amounts of particulate matter in the gas stream. Continuous gentle agitation promotes combustion and limits particulate entrainment. Combustion is largely achieved by air passing through the waste bed from under the grate, but excessive amounts of underfire air contribute to particulate entrainment.[4] Some inert materials, such as glass bottles and metal cans, aid combustion by increasing the porosity of the fuel bed. Conversely, inert materials inhibit combustion if the materials clog the grate openings.

The rotary kiln has a solid refractory surface and is commonly preceded by a reciprocating grate. The slow rotation of the kiln, which is inclined, causes the solid waste to move in a slowly cascading and forward motion.

The circular grate, in the vertical circular furnace, is commonly used in combination with a central rotating cone grate with extended rabble arms that agitate the fuel bed.

Solid waste is charged either continuously or in batches. In the continuous process, solid waste is fed to the furnace directly through a rectangular chute that is kept filled at all times to maintain an air seal. In the batch process, solid waste is fed to the furnace intermittently through a charging gate or hatch, which is closed except when waste is being charged. The waste may be stored in a hopper and fed intermittently through a chute, or the furnace may be fed directly by opening the charging gate and dropping the waste directly from a crane bucket, front-end loader, or bulldozer. A ram can also be used to feed a batch of material directly to the gate through an opening in the furnace wall. Continuous feed minimizes irregularities in the combustion system. Batch feeding causes fluctuations in the thermal process because of the non-uniform rate of feeding and intermittent introduction of large quantities of cool air.

Grate systems may be classified by function, such as drying grate, ignition grate, and combustion grate. Grates for solid waste incineration may also be classified by mechanical type. They include traveling, reciprocating, rocking, rotary kiln, circular, vibrating, oscillating, and reverse reciprocating grates; multiple rotating drums; rotating cones with arms; and variations or combinations of these types. In the United States, traveling, reciprocating, rocking, rotary kiln, and circular grates are the most widely used.

Traveling grates are continuous, belt-like conveyors. A single traveling grate does not promote agitation. Two or more grates at different elevations provide some agitation as the material drops from one level to the next.

In reciprocating grate systems, the grate sections are stacked like overlapping roof shingles. Alternate grate sections slide back and forth while adjacent grate sections remain fixed. Like traveling grates, reciprocating grates may be arranged in multiple-level series providing additional agitation as the material drops from one grate to the next.

Rocking grates are arranged in rows across the width of the furnace, at right angles to solid waste flow. Alternate rows are mechanically pivoted or rocked to produce an upward and forward motion, thus advancing and agitating the solid waste. Rocking grates have also been arranged in series.

Siftings are the fine materials that fall from the fuel bed through the grate openings during the drying, ignition, and burning processes. Siftings consist of ash, small fragments of metal, glass and ceramics, and unburned or partially burned organic substances. In some designs, siftings are collected in troughs and conveyed continuously by sluicing or mechanical means to a residue collection area. In other designs, siftings are collected and returned continuously by a conveyor to the furnace.

Residue - all solid materials remaining after burning - includes ash, clinkers, tin cans and other metal pieces, glass, rock, and unburned organic substances. Residue removal can either be a continuous operation or an intermittent batch process. In a continuous feed furnace, the greatest volume of residue comes off the end of the burning grate; the remainder comes from siftings and from fly ash. The residue from the grate must be quenched and removed from the plant.

For a substance to burn, both surface and internal moisture must be driven from the material. Once moisture is removed, the temperature of the substance can be raised to the ignition point, although the outer surface of a solid may be dried and ignited before the inner material is dried. This drying process continues throughout the entire length of the furnace, but proceeds at the greatest rate immediately following charging of the solid waste.

The combustion process in incineration is thought of as occurring in two overlapping stages, primary combustion and secondary combustion. Primary combustion generally refers to the physical-chemical changes occurring in proximity to the fuel bed and consists of drying, volatilization, and ignition of the solid waste. Secondary combustion refers to the oxidation of gases and particulate matter released by primary combustion. Secondary combustion achieves combustion of unburned furnace gases, elimination of odors, and combustion of carbon suspended in the gases. To promote secondary combustion, a sufficiently high temperature must be maintained, sufficient air must be supplied, and turbulence or mixing should be imparted to the gas stream.

The function of turbulence is to ensure mixing of each volume of gas with sufficient air for complete burning of volatile combustible matter and suspended particulates. The turbulence must be intense and must persist long enough for mixing to be completed while the temperature is still high enough to ensure complete burning.

In the combustion process, oxygen is needed to complete the chemical reaction involved in burning. The air necessary to supply the exact quantity of oxygen required for the chemical reactions is termed stoichiometric or theoretical air.

Any additional air supplied to the furnace is termed excess air and is expressed as a percentage of the theoretical air.

Air that is purposely supplied to the furnace from beneath the grates is termed underfire air. Overfire air is that air introduced above the fuel bed; its primary purpose, in addition to supplying oxygen, is to provide turbulence. Infiltration air is the air that enters the gas passages through cracks and openings and is frequently included in the figure for overfire air.

The proportioning of underfire air and overfire air depends on incinerator design. Very often, the best proportions are determined by trial and error. For most municipal incinerator designs, underfire air is from 40 to 60 percent of the total air. (Total air is the total of all underfire, overfire, and infiltration air). This amount of underfire air provides acceptable combustion in the fuel bed and adequate grate cooling. In general, as the underfire air is decreased, the burning rate is inhibited.

To supply adequate air for complete combustion and to promote turbulence, a minimum of 50 percent excess air should be provided. Too much excess air, however, can be detrimental because it lowers furnace temperatures. In general, refractory furnaces require 150 to 200 percent excess air, whereas water tube wall furnaces require only 50 to 100 percent excess air.

The burning of solid waste generates heat that expands the volume of gas. The gas passages, air pollution control devices, and stack must satisfactorily accommodate this gas. An estimate of the quantities of gaseous products of combustion can be calculated from the ultimate analyses of solid waste. Gas velocities must be determined so that gas passages can be sized to prevent excessive settlement of entrained particles.

Incinerator stacks provide natural draft and dispersion for gases and particulate matter. Accordingly, the height and diameter of the stack depend upon the amount of draft required and the topographic and climatic conditions. If necessary, induced draft fans should be used to supplement the natural draft in moving gases through the incinerator.

To adequately control the combustion process, the draft must be regulated. Dampers are generally used in both natural draft stacks and in stacks employing induced draft fans of constant speed. Adjustable speed, induced draft fans are also used to control draft. Under most conditions, an induced draft fan is preferred over natural draft stack. Control over the burning solid waste can be better maintained and air pollution collection devices better operated with the constant air volume and uniform pressure drop that the induced draft fan creates.

Adequate temperature, time, and turbulence are necessary to completely burn the gases and carbon suspended in the gases and to destroy the odors. If temperatures are too low, the oxidation reactions are incomplete; if too high, the temperatures can cause equipment and structural damage throughout the incinerator. Excessively high temperatures can cause refractories to fail through excessive expansion, can cause slag buildup on the furnace linings, or may produce oxides of nitrogen. When the air stream is suddenly cooled, these nitrogen oxides do not have time to decompose to nitrogen and oxygen. Because of variations in composition and density of the solid waste, careful operation is required to maintain furnace temperatures within the desirable range.

At the air intake, combustion air is at ambient temperature. Combustion air may be preheated to 200 to 300°F. Once in the furnace, the temperature rapidly rises. Immediately above the burning waste, the temperature of the burning gases generally ranges from 2,100 to 2,500°F, and for short periods of time, it may reach 2,800°F in localized areas. When the gas leaves the combustion chamber, the temperature should be between 1,400 and 1,800°F. The gas temperature entering the stack can be expected to be 1,000°F or less. Where induced draft fans, electrostatic precipitators, and other devices requiring lower gas temperatures are used, the gases will have to be cooled further. Before they enter the air pollution control devices, the gases should be cooled to 500 to 700°F.[5]

In a batch feed incinerator, opening the charging door lowers the temperature of gases in the combustion chamber by as much as 500°F. Introducing extremely high or low Btu wastes can also cause abrupt and extreme temperature change.

Furnace temperature varies considerably, depending on where it is measured. The most widely accepted location for measuring and reporting furnace temperature is near the roof at the exit of the combustion chamber. At this location, the temperature should be maintained between 1,400 and 1,800°F to ensure that proper combustion has occurred.

Regulation of the combustion process through control of furnace and flue gas temperatures is achieved principally through the use of excess air, water evaporation, and heat exchange. Of these, the use of excess air is the most common and, in refractory furnaces, is often the only method of control. Even when another cooling method is available, some excess air is still used by primarily for ensuring turbulence and complete combustion.

The purpose of excess air is to cool and mix the hot gases through a dilution process, which lowers gas temperatures. The cooler ambient air is mixed with the hot combustion gases, and an equilibrium temperature is reached.

Water injected into the hot gas stream cools the flue gas through evaporation of the water and absorption of heat during superheating of the water vapor. Although the water vapor adds to the total gas volume in a manner similar to the addition of excess air, the total of water vapor and cooled gases is smaller than the original volume of gases. Some economy may result from reducing this volume of gas to be treated; however, the cost of water should also be considered. Water cooling is used on flue gases but is not generally employed in cooling the furnace.

Although heat exchange through the use of water tube walls and boilers is not in widespread use in the United States, it is attracting greater attention and is employed in Europe. A distinct advantage of heat exchangers in cooling gases is that additional gases or vapors are not added to the gas flow to reduce temperature and significantly smaller gas volume results. Because gas volume is greatly reduced, the size of collection devices, fans and gas passages can be reduced. Heat recovery and utilization can bring further economies.

Water tube wall furnaces are made of closely spaced steel tubes welded together to form a continuous wall with water or steam circulating through the tubes. The water tube wall furnace offers greater control over temperatures and provides an air-tight enclosure. These furnaces have been used successfully in the power industry and in some European incinerators for many years; however, their installation in

municipal incinerators in the United States has been limited.

It is desirable to have auxiliary fuels available for (1) furnace warm up; (2) promotion of primary combustion when the solid waste is wet or does not contain an adequate Btu content for good combustion; (3) completion of secondary combustion to ensure odor and smoke control; (4) supplementation of heat for heat recovery units when the supply or heat value of the solid waste is not sufficient.

Auxiliary fuel is usually gas or oil. Burner location depends on the purpose of the auxiliary fuel. The use of auxiliary fuel has not been common practice in the United States.

3.0 EMISSIONS

The air pollutants arising from municipal incineration of solid wastes fall into three categories: mineral particulate; combustible solids and gases; and non-combustible gases. Particulate emissions from municipal incineration has been estimated at 100,000 tons per year.

Combustible refuse contains nitrogeneous constituents which, under normal conditions, can liberate oxides of nitrogen, the most common of which are NO_2, NO and N_2O_3.

Sulfur is present in protein material as a basic building block. Degradation of sulfur-containing molecules in an incinerator produces the sulfur oxides.

Particulates from refuse incineration originate from dust raised in the refuse dumping and handling processes, smoke discharged through semiporous furnace walls and stoking doors, and entrained dust in the gases discharged from the furnaces. The first two are minor sources and are extraneous to the burning process.

The mass emission rate for particulates from the combustion process is a function of many variables: (1) undergrate air velocity; (2) refuse ash content; (3) burning rate or combustion quality; (4) grate agitation in a continuous feed incinerator; (5) size, method, and frequency of feeding for batch units; and (6) combustion chamber design. Items 1 and 2 are the major factors.

A systematic study by the Public Health Service of the effects of underfire air, secondary air, excess air, charging air, stoking interval, and fuel moisture content on particulate emission rates from an experimental incinerator led to the conclusion that the velocity of the underfire air was the dominant factor influencing the emission rate. Subsequent field evaluation of emission rates from municipal units indicated that the effect of underfire air rate was less pronounced than that observed in the experimental unit.

Mineral particulate, the incombustible fraction of fly ash, is composed mainly of the mineral matter in waste that is entrained by the combustion air or combustion products. Oxidation of metals and subsequent volatilization or entrainment of the metal oxides contributes also to the mineral particulates, but is a minor fraction of the total loading.

Combustible particulate comes from three sources: char entrained from the grate; soot produced by thermal cracking of pyrolysates; and the aerosol of condensed, unreacted hydrocarbons and oxygenates.

The following table shows typical emission levels from uncontrolled municipal incinerators of total particulate, sulfur oxides and nitrogen oxides.

Pollutant Levels in Incinerator Flue Gas

Species	Furnace Emission	Reference
NO_x (as NO_2)	2.1 lbs/ton refuse	Day and Zimmerman R
	0.15 - 1.5 ppm	Day and Zimmerman R
	0.2 - 0.33 lbs/1000 lbs dry flue gas	Day and Zimmerman R
	2.7 lbs/ton refuse	BSWM Report[2]
	3.0 lbs/ton refuse	A.D. Little Report[3]
SO_x (as SO_2)	1.9 lbs/ton refuse	Day and Zimmerman R
	0.25 - 1.2 ppm	
	3.9 lbs/ton refuse	A.D. Little Report
Particulate	3 lbs/1000 lb flue gas	Day and Zimmerman R
	1.61 grain/SCF at 150 percent excess air	
	10 - 60 lbs/ton refuse	BSWM
	19.7 lbs/ton refuse	A.D. Little
	17 lbs/ton refuse	NAPCA[4]

1) Special Studies for Incineration. Report by Day and Zimmerman to the United States Department of Health, Education and Welfare, 1968.

2) Incineration Guidelines by J. DeMarco, D.J. Keller, J. Leckman, and J.L. Newton, PHS Publication No. 2012, 1969.

3) Systems Study of Air Pollution from Municipal Incineration, Report by Arthur D. Little to the National Air Pollution Control Administration, March 1970.

4) Control Techniques for Particulate Air Pollutants, (AP-51), U.S. Department of Health, Education, and Welfare, National Air Pollution Control Administration, Washington, D.C. (1969).

4.0 CONTROL TECHNOLOGY

4.1 Control of Gaseous Emissions from Combustion. Both nitrogen oxide and sulfur oxide emissions occur in solid waste incineration, but the amounts per ton of fuel burned are several orders of magnitude below those involved in the combustion of fossil fuel. Solid waste is inherently a "clean fuel" from the standpount of sulfur content, with a value of about 0.16 percent by weight as compared to most coals and residual oils used today, which range from about 1 to 3 percent sulfur. Further, there is evidence to suggest that for incineration, most of the sulfur is retained in the ash rather than as oxides in the stack. Thus, sulfur oxide emissions from solid waste incineration generally are well below even the most stringent restrictions, present or anticipated.

Restrictions on nitrogen oxide emissions from fossil fuel combustion have not yet been formulated. Nitrogen oxide emissions per ton of fossil fuel are over 10 times greater than those in an incinerator. Therefore, it appears unlikely that this contaminant will be regulated in incinerator plants in the near future.

4.2 Control of Suspended Particulate Emission from Combustion. The following is a brief discussion of the various types of particulate collection systems, their performance capabilities based upon objective test data, the state of the art of their development with respect to application to incinerators, and some general indication of their capital cost. Cost data are

based upon plants in the range of 150- to 200- ton-per-day rated capacity. The particular type of control system used will depend primarily on the desired level of control, taking into account both quantitative and optical emission criteria, and on the overall cost to build and operate the system.

4.2.1 Types of Collectors. Settling Chambers. The simplest and oldest form of particulate collector is the settling chamber with either a dry or wet bottom. With the exception of a very few plants equipped with some form of sprays or baffle system within the settling chambers, this was the only type of collector used in incineration plants in this country before about 1953 or 1954. Available test data on the settling chamber indicate efficiencies in the range of 10 to 34 percent by weight.[6,7,8] Since 1961 and 1962, the use of settling chambers in their simplest form as the only particulate collection device has become essentially obsolete since they are unacceptable as the principal means of air pollution control.

4.2.2 Wetted Baffle-Spray. Another form of particulate collection device is the wetted baffle or baffle spray system. These systems usually consist of vertical impingement baffle screens that are wetted with water by flushing sprays or overflow weirs. There may be one or more screens in the collection system. Particulate removal efficiency has been measured over a range of 10 to 53 percent by weight at several different installations.[6,7]

Pressure drop is in the range of 0.3 to 0.6 in. of water gauge. Water consumption is in the range of 0.5 to 2.0 gal. per min per ton rated capacity. One installation, which uses a spraying section and secondary baffle section, claims an efficiency of 69.4 percent; pressure drop and other operating data are unavailable.[8]

These wet spray or wet baffle systems have been used on over half of the incinerators installed since 1957. Their installed cost if approximately $0.02 to $0.04 per actual cu ft per min of gas at the collector inlet temperature (1,800?).

4.2.3 Cyclones and Multiple-Cyclones. Batteries of relatively large diameter (24 to 40 in.) parallel cyclones, with involute or scroll type entry connections, as well as small diameter (9 to 12 in) multiple tube vane type cyclone collectors have been used in about 20 percent of the incinerator installations built ot under construction since 1957. Although there is a substantial amount of test data available on the performance of this type of collector, little has been published. Unpublished data confirm published data that indicate efficiencies in the range of 60 to 65 percent.[8] There is little information on the performance characteristics of the small diameter vane type collectors. Experience in a few installations seems to indicate that plugging of this type collector can be a problem when used downstream of gas cooling systems involving the use of water.

Experience with cyclones seems to favor the use of the involute type in tube size above 24 in. Maximum reliable efficiency appears to be in the range of 70 to 80 percent.[9] Pressure drop is in the range of 2.5 to 4.0 in. water gauge.

Installation cost for cyclone collectors, not including such auxiliaries as foundations, supporting steel, flues, and ash removal, is in the range of $0.12 to $0.25 per actual cu ft. per min of gas treated.

4.2.4 Wet Scrubbers. Approximately 20 percent of the incinerator plants built or under construction since 1957 have been equipped with wet scrubbers. Wet scrubbers differ in their design and operation from wetted baffle collectors principally in that capture of the entrained particulates is accomplished by direct intimate contact of the particulates with the water itself rather than on water-flushed impaction surfaces. The particulates collide with water droplets to effect capture. The water droplets and impacted particles coalesce into larger droplets (greater than 1,000 microns) that are easily collected in an inertial collector. The water droplets are generally formed by either atomizing the liquid into the gas stream or by allowing the gas stream to tear coarse water droplets into the smaller droplets needed for high efficiencies. With atomizing units, most of the operating energy is expended in pumping the water through the spray nozzles; gas pressure drops are generally low.

Three of the more recent innovations in medium and high energy wet devices are the impingement plate (Peabody and Sly), the fluid bed or "ping pong" ball (by UOP), and the venturi scrubber (by Chemico).

In units where the gas stream tears the water apart, most of the operating energy is expended in moving the gases through the unit: comparatively little energy is consumed in pumping water. In scrubbers, collection efficiency is primarily related to total energy consumption whether it is energy used to pump liquid or energy used to move gas. Again, published test data are unavailable on this type collector, but analysis of their operating principles and comparision of their known performance on suspended particulates with characteristics similar to those from incineration indicate an efficiency capability in the range of 94 to 96 percent at pressure drops in the range of 5 to 7 in. water gauge.

Water requirements range from about 5 to 15 gal per 1,000 actual cu ft per min of gas treated. Pumping power is based on these figures, although actual make-up water requirements can be much lower where recirculating and clarification systems are utilized. Another characteristic of wet scrubbers is that the gases at the collector outlet will be saturated with water vapor, an important consideration in relation to water vapor plumes from the stack.

Because they operate below the dewpoint of many trace corrosive constituents in incinerator flue gases, wet scrubber systems require corrosion-proof construction. The installed cost for the base collector without auxiliaries such as foundations, water treatment systems, pumps, and piping ductwork is in the range of $0.25 to $1.25 per actual cu ft per min of gas treated.

4.2.5 Electrostatic Precipitators. Electrostatic precipitators operate on the principle of electrically charging the suspended particulates and depositing the charged particles on the surface of a collecting electrode. To remove the particles from the collecting electrode, the collecting surface is vibrated although water sluicing can be used in certain applications.

The electrical properties of the suspended particles, the moisture content of the gas stream, and the temperature of the gas stream affect precipitation operation. Adding moisture can lower the high resistance of inorganic particles. The tendency of carbon to lose its charge before collection can cause some problems, but these can be overcome. Proper insulation of the precipitator, which eliminates the internal dewpoint condensation, can control corrosion caused by moisture in the gas stream. Temperature of the gases is very important to precipitator operation because the resistivity of entrained particles is extremely temperature dependent. Precipitator operation is best at temperatures between 470 and 520 F.[10]

Electrostatic precipitators have no ability to collect gaseous contaminants except as these gaseous contaminants may be absorbed on the particulates removed.

Electrostatic precipitators have been used in Europe for a number of years in incinerator plants that recover heat. Auxiliary fuels such as coal or oil are used under most operating conditions.[11] Efficiencies in the range of 96 to 99.6 percent have been achieved at pressure drops below 0.5 in. water gauge. Electrical power requirements are in the range of 200 to 400 watts per 1,000 actual cu ft per min of gas treated. Inlet temperatures are usually in the range of 350 to 700 F.

During pilot plant feasibility tests, efficiencies of 89 to 94.4 percent were obtained on suspended particulate removal from a 220-ton-per-day continuous feed furnace.[12] Electrostatic precipitators have not yet been operated on a full scale basis in the United States, but several new plants under construction will utilize electrostatic precipitators with design efficiencies in the 90 to 98.5 percent range. The basic advantage of the electrostatic precipitator over other particulate collectors is its high efficiency at low operation cost (pressure drop and electrical power input) and its ability to achieve these efficiencies in a dry system without creating potential water pollution problems. Typical installed cost for electrostatic precipitators, not including auxiliaries such as foundations, supporting steel, flues, and fly ash removal, is in the range of $0.85 to $1.45 per actual cu ft per min of gas treated.

4.2.6 Fabric Filters. Except for a single pilot installation on one municipal incinerator, fabric filters have not yet been applied to incinerators. Although they are used by many industries, their use at incinerators must be considered experimental.

Fabric filters literally filter the suspended particulates from gases in a manner sililar to the operation of a vacuum cleaner. The predominant filtering media is the dust cake itself, which accounts for the high efficiencies obtainable (usually in the 99.9% + range).[9] The dust cake once it has been formed, essentially filters all particles as the gases pass through the pore openings in the cake; these openings are no bigger than the smallest particle in the gas stream.

Their utilization for a given application is almost always based on consideration of temperature, moisture content of the gas stream, pressure drop characteristics of available filtration media, and the service life of these filter media. Fabrics such as fiberglass and high-temperature synthetics, are available with continuous operating temperature capability up to about 550 F. Many varieties exist, and their costs differ principally in relation to their temperature capability and resistance to chemical attack. Another consideration in the selection of fabric filters is the porosity of the filter cake that is built up on the fabric surface during normal operation.

Cake porosity depends on moisture, particle size distribution, and physical and chemical characteristics of the entrained particulates. The typical operating pressure drop for fabric filters would be in the range of 4 to 7 in. water gauge. Initial cost of fabric filters that might be applied to incinerator operations, based upon the use of treated fiber-glass bags, would be in the range of $0.75 to $1.50 per actual cu ft per min of gas treated.

4.3 Control of Water Vapor Plumes. Water vapor plumes may not be directly harmful and are, in most cases, excluded from opacity regulations. Droplet fallout or visible vapor plumes, however, may constitute an important nuisance factor. Usually the plume problem is associated with high efficiency wet scrubbers, so the first method of controlling condensate plume is to use dry gas cooling and collecting techniques. If other factors dictate the use of high-efficiency scrubbers two alternatives are possible: (1) extract heat from the hot furnace gases before collection and reintroduce the extracted heat after collection as stack gas reheat. Such a scheme which involves the use of gas-to-gas heat exchangers, reduces both absolute and relative humidity of the stack gases and improves their dispersion capability at the same time (such systems have been used on incinerators); (2) dehumidfy the saturated flue gases by subcooling below the normal scrubber outlet temperatures. Cooling requires the use of a packed cooling tower and a source of cooling water below the wet scrubber exhaust gas temperature. Dehumidification of the

stack gases can be achieved by this method, water can be recovered and recycled, and the operating horsepower of high pressure drop fans can be reduced. Dehumidification systems have been used with success in other applications, but have not, as yet been utilized on incinerators.

5.0 MUNICIPAL INCINERATORS UTILIZING BEST EMISSION CONTROL TECHNOLOGY

Because the main reason for refuse incineration is volume reduction and sterilization, plants too often have been built and operated without adequate consideration for emission control. The literature shows that the furnace design and operating practices of municipal incinerators are major factors influencing residue quality and burnout, but have lesser effect on effluent material. Mineral particulate emissions, for example, are practically independent of incinerator design; combustible solids and gases emissions are much more influenced by design and operation parameters. Air pollution control systems have a reverse influence on incinerator effluent, having a much stronger effect on mineral particulate than combustibles emissions. Emission of noncombustible gaseous pollutants are a slight function of design and operating practices, but are a strong function of refuse composition. These non-combustibles are affected variably by the air pollution control system used.

A principal consideration in minimizing the emissions of air pollutants from municipal incinerators is employment of appropriate air pollution control systems for the control of mineral particulate. Effective control of combustible pollutant emissions should be directed more toward minimization of pollutant formation and/or maximization of ensuing destruction rates.

The use of air pollution control systems are ~~the~~ most effective in reducing mineral particulate emissions and are the only means of reducing ~~stack~~ emissions of the non-combustible pollutants. In this study evaluation of effectiveness of existing air pollution control was limited by the lack of available efficiency test data on municipal incinerators. Most tests measure emissions only at the stack. Thus, efficiencies are calculated from theoretical models.

Pollution control for incinerators is essentially particulate control. Substantial technology exists to control this pollutant. A major question arises, however, in the area of particulate emissions. Particulate definition must be related to the testing methods used to obtain emission data.

Two particulate sampling techniques which differ in particulate definition are the American Society of Mechanical Engineers (ASME) Performance Test Codes (PTC 21 and 27) and National Air Pollution Control Administration's (NAPCA) filtration-condensation test procedure. The ASME test determines solid particles filterable by dry filtration methods. The NAPCA "total particulate" includes also the condensable organics and sorbable gases which are trapped at ice-bath temperatures. Mr. Fred R. Rehm, Director, Department of Air Pollution Control, Milwaukee County, Wisconsin raised

some interesting questions regarding these two sampling methods at the 1970 National Incineration Conference held by the ASME in Cincinnati, Ohio this past June, 1970. A copy of his open letter addressed to various individuals, government agencies, and professional organizations prior to this conference appears in the appendix of this report.

Air pollution control systems for municipal incinerators are traditionally selected in an attempt to meet the local emission code. The selections are also reflections of the relative importance of investment versus operating cost trade-offs and of local constraints such as utilities cost, operator qualifications, waste water disposal considerations and aethetics. As a result air pollution control device selections are made on case-by-case basis, considering the requirements of each plant location and the locally established plant performance objectives. For these reasons, maximum available air pollution control technology is seldom, if ever, a consideration in design and construction of present day municipal incinerators.

A purpose of this study, however, included the search for the best utilized air pollution control technology for existing municipal incinerators, both domestic and world-wide. A very complete listing, with general description, of all domestic municipal incinerators is available (A.D. Little Report, Volume 1, Chapter 11-3). From this inventory, a selected group of candidate incinerator facilities were

examined more closely in order to determine the effectiveness of the control technology currently in use. (See Table 5-1).

Table 5-2 shows the "best" municipal incinerator from an air pollution viewpoint, tested thus far by the Bureau of Solid Waste Management. The average total particulate is 0.34 grains per standard cubic foot at 12% CO_2. The lowest solid particulate grain loadings are 0.07 to 0.09 for medium energy wet scrubbers; 0.09 for the pilot tested venturi and 0.03 to 0.05 for the electrostatic devices. Chemico Corporation indicated verbally that the venturi could achieve 0.05 grains/SCF at a 9" pressure drop and 0.01 at an 30" pressure drop.

In conclusion, it appears that maximum air pollution control of total particulate could be best achieved by using the high energy venturi wet device. If condensables and adsorbable particulate matter can be otherwise minimized, eliminated, or ignored, maximum control for solid particulate would use the electrostatic precipitator.

6.0 CURRENT EMISSION REGULATIONS FOR MUNICIPAL INCINERATORS

The principal gaseous emissions from municipal incineration are carbon dioxide, water vapor, nitrogen and oxygen for which no controls are necessary. In recent times, attention has been directed toward the control of sulfur oxides, nitrogen oxides, carbon monoxide, hydrogen chloride and total hydrocarbon emissions from a variety of sources. Except for sulfur oxides, maximum permissable emission levels have not been developed. Criteria does exist in certain critical areas, however, on nitrogen oxides and total hydrocarbons. In the case of solid waste incineration, emissions of all these gaseous contaminants is well below present or contemplated criteria. With the possible exception of the control of those trace emissions that cause odors and, as yet undefined, chemical toxicants, the control of gaseous emissions from municipal incineration is of secondary concern.

Gas suspended particulate matter is the primary concern. Specific quantitative emission limits on gas-suspended particulates are becoming increasingly prevalent in the air pollution codes of many municipalities and States as well as in the operation of Federal facilities. These codes may be expressed in a variety of ways, such as: (1) total weight of suspended particulate per unit volume of exhause gases; (2) total weight of suspended particulate per unit weight of exhaust gases; (3) total weight of suspended particulate

emitted per unit weight of solid waste charged. Further, to prevent compliance with emission codes by simple dilution of stack gases with air or water vapor, almost all codes require correction of these emission limits to a specific reference condition.

At the present time, the most commonly used units for emission values in incinerator practice are pounds suspended solids per thousand pounds of dry flue gas corrected to 50 percent excess air and grains per standard cubic foot (29.92 in. Hg and 70 F) of dry flue gas corrected to 12 percent carbon dioxide. The reference conditions of 12 percent carbon dioxide and 50 percent excess air are approximately equivalent for municipal solid waste.

Some representative gas suspended particulate emission limits have been summarized in the following table.

Emission standards specific for incinerators are relatively new and are undergoing revision. Los Angeles County has for many years enforced a concentration standard of 0.3 grain per standard dry cubic foot, corrected to 12 percent carbon dioxide, without the contribution of auxiliary fuel. This was a level felt to be attainable with well-designed, multiple-chamber incinerators, without control equipment. In 1966, the Federal Government applied this standard to its incinerators smaller than 200 pounds per hour and required larger units to meet a standard of 0.2 grain per standard dry cubic foot corrected to 12% CO_2. The latter was found to be attainable

with installation of certain low-efficiency wet collectors, operating at pressure drops of about 0.5 inch of water. These particular standards have been adopted by many other control agencies in the past few years. The State of New Jersey requires that incinerators with capacities greater than 2000 pounds per hour meet a standard of 0.1 grain per standard dry cubic foot, and smaller ones a standard of 0.2 grain per standard dry cubic foot. (Corrected to 12% CO_2).

In 1967, New York City and New York State developed standards that restrict mass-emission rate in pounds per hour as a function of increasing, incinerator size, as determined by total weight rate of refuse charged in pounds per hour. This is more logical than concentration standards, which are somewhat difficult to standardize for percent of carbon dioxide, if auxiliary fuel is used or if a wet collector is employed. Furthermore, it is more meaningful to restrict mass-emission rate than to restrict effluent concentration.

The standards for Federal Facilities (0.3 and 0.2 grain per standard dry cubic foot, corrected to 12% CO_2) have been converted to equivalent mass-emission rates on the basis of selected normal refuse. These converted standards, the basis for conversion, and the New York City and New York State regulations are shown in Figure 6-1. The regulations for Federal Facilities represent constant emission concentrations and, hence, require about the same degree of collection efficiency for all incinerators with capacities above and below 200 pounds per hour.

Parallel regulations (e.g., New York State's existing units) also ~~represents~~ require a single concentration and constant collection efficiency for all sizes. This is less than ideal for reasons already discussed. Larger units discharge more pollutants and are better suited to installation of more efficient collectors.

In addition to provisions limiting the quantities of particulate emission, many codes at the municipal and State level also have opacity restrictions - usually based upon the Ringelmann Chart. The Ringelmann number is determined by a comparative visual observation of the stack plume and a series of reference grids of black lines on white that, when properly positioned, appear as shades of gray to the observer. Although the quality of a plume in equivalent Ringelmann numbers is not easy to determine, trained observers, properly positioned in relation to stack, sun, and wind direction, can provide satisfactorily consistent evaluations. Water vapor plumes complicate observations of stack gases.

The trend in most codes on incinerator emissions based on Ringelmann is to require that: (1) normal continuous plume quality not to exceed Ringelmann No. 1; (2) for short periods not exceeding 3 to 5 minutes in any one hour, plume quality not exceed Ringelmann No. 2, and (3) plume quality clearly resulting from water vapor only be excluded from regulation.

Plume opacity refers to the inability of light to pass through the gas plume and is usually applied in cases where the plume is some color other than gray or black. Opacity readings are expressed in terms of percent visibility through the gas plume.

From the standpoint of plant design, a basic problem arises from the fact that the entire technology of particulate collection has been based upon quantitative reduction in the weight of total suspended materials. Thus, to establish the level of control required to meet a given visual code, this code must be expressed in some quantitative gravimetric units. Consistent and general criteria for correlating gas quality measurements, such as Ringelmann number, with quantitative emission in the case of incinerators are not yet available. Therefore, the collection efficiency required to meet a particular Ringelmann number is virtually impossible to predict. Experience with large, coal-fired steam generators indicates that loadings in the range of 0.01 to 0.02 gr. per cu. ft. of exit gas result in stacks optically clear of suspended particulates (i.e., less than Ringelmann No. 1). Achievement of these stack concentrations in coal firing requires collector efficiency in excess of 99 percent by weight. Similarities in particle size distribution from coal-fired steam generators and from incinerators indicate that efficiencies of this order will be required on incinerators if completely clear stack emissions are to be achieved.

7.0 RECOMMENDED EMISSION LEVELS FOR NEW INCINERATORS

To provide a two-fold basis for recommendation of national standards for particulate emissions from municipal incinerators, both the theoretically achievable levels as well as actual test data were considered:

The theoretical approach involved a calculation of municipal incinerator uncontrolled furnace emissions based on the NAPCA particulate emission factor for refuse incineration and the Kaiser[13] refuse combustion stoichiometry. The theoretical or stoichiometry air for combustion of municipal refuse has been calculated from the ultimate analysis of the refuse on an as-fired basis, as 3.16 pounds of dry air per pound of refuse.[13] This value is equivalent to 42.3 cubic feet of dry air per pound of refuse or 63.5 cubic feet, corrected to 50% excess air.

Uncontrolled furnace emissions can be calculated from this number and the NAPCA emission factor:[14]

$$\frac{17 \text{ lbs particulate/ton (refuse)} \times \frac{7000 \text{ grains}}{\text{pound}}}{\frac{63.5 \text{ SCF}}{\text{lb (refuse)}} \times \frac{2000 \text{ lb}}{\text{ton}}} = 0.925 \text{ grain/SCF at 50\% excess air } (\sim 12\% \ CO_2)$$

At 95% control efficiencies, stack emissions would be 5% or 0.046 grain/SCF (at 12% CO_2); at 99% control, stack emissions would be 1% or 0.009 grain/SCF (at 12% CO_2).

To further substantiate these theoretical values, stack emission data from the best controlled municipal incinerators were further evaluated to determine the frequency and level of

the lowest measured particulate loadings. The Issy, France facility has 6 data values equal to or below 0.01 grains/SCF at 12% CO_2 and 27 additional data values at or below 0.03 grains/SCF at 12% CO_2 (out of a total of 43 data values). The Chemico Venturi scrubber pilot test on the East 73rd St. facility had a single measured value (out of 6) of 0.009 grains/SCF at 12% CO_2. This outlet loading of solid particulate was measured at a 9 inch pressure drop, which corresponds to a 95 to 96% collection efficiency. At pressure drops in the 20 to 30 range, collection efficiency can be expected to approach 99%.[15]

The most stringent foreign emission regulation for particulate matter from municipal incinerators is equivalent to 0.079 grains/SCF (dry) at 12% CO_2. The proposed Maryland regulations at 0.03 grains/SCF (dry) at 12% CO_2 is the most stringent domestic regulation. With proper furnace and grate design plus careful operation, the non-solid particulate loading could be substantially reduced from municipal incinerator flue gas. Because the ever-changing nature of the refuse feed fluctuates in moisture content as well as other variables, it is expected that total particulate emissions will always be somewhat higher than the solid particulate loadings. Preliminarily, it would seem proper to consider setting two emission standards on a national basis; one for total particulate, the other for solid or dust loadings. Maximum technology is available in the form of electrostatic precipitator to ensure solid particulate emissions at or below 0.01 grains/SCF (dry) corrected to 12% CO_2. Total particulate emissions can be kept at or below 0.03 grains/SCF (dry) with the venturi scrubber.

It is recommended that the National Emission Standards for particulate matter from municipal incinerators be based on these two figures.

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